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UNITS

D. P. Pampura and A. K. Masliy

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16. Abstract A model study is presented of drives for the electro- magnetic clutches used in the hoists. Equations are set up and solved, describing the principles of the slip variation during the transient period of the plate en- gagement.			
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DYNAMICS OF DISCONNECTABLE MICRODRIVES OF MINE HOISTING UNITS

D. P. Pampura and A. K. Masliy

Set forth in the present study are the results of the study of the dynamics of a two-speed microdrive with an electromagnetic friction clutch. An electrodynamic model was developed in the State Institute for the Design and Planning of Electric Mine Equipment for this purpose. The method selected for studying the dynamics is advisable primarily because it makes it possible to study the dynamics of the full-scale unit on a laboratory model with great reliability, and to correctly select the design and parameters of the microdrive, even in the development stage.

/1002*

Given in figure 1 is the block diagram of a mine hoisting unit with a disconnectable microdrive and an electrodynamic model of it. We will designate the total moment of inertia of all of the elements of the hoist system connected with the driven portion of the clutch and relative to the shaft of this clutch by I_1 , and that of all of the elements connected with the driving portion of the clutch by I_2 .

The parameters of the electrodynamic model of the disconnectable microdrive are established based on the criteria of similitude, according to the basic factors which affect the dynamics of the drive [1]. The scale factor of the model is equal to 4.

The moment of force on the driven shaft of the model is provided using an adjustable mechanical brake 4 under conditions of inspection of the shaft and cables, and by means of

*Numbers in the margin indicate pagination in the foreign text.

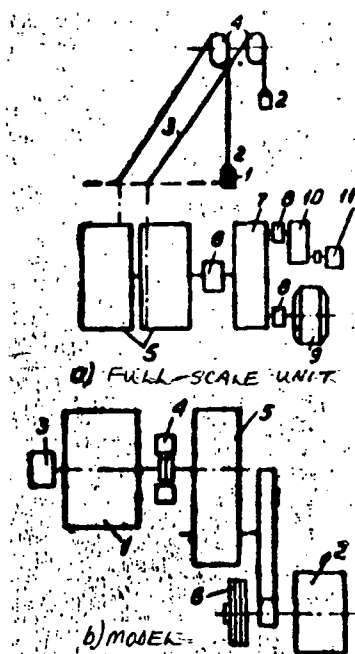


Fig. 1. Block diagram of hoisting unit with disconnectable two-speed microdrive: a) full-scale unit; 1—effective load; 2—skips; 3—cables; 4—blocks; 5, 7, 9—hoisting machine, reduction gear, and engine; 6, 8—main and flexible couplings; 10, 11—microdrive reduction gear and engine; b) model: 1, 2—main and auxiliary engines; 3—tachogenerator; 4—mechanical brake; 5—reduction gear attachment with electromagnetic friction clutch; 6—device for controlling the moment of inertia.

electrodynamic braking of the main engine 1 under conditions of the hauling up of containers. Different ratios of the moments of inertia $I_1:I_2$ are reached using a device 6 with calibrated plates, the moments of inertia of which are selected with the condition that the ratios $I_1:I_2$ corresponding to the actual units are obtained (0.6-1.1).

The most important element of the model being studied is the electromagnetic friction clutch, built into a reduction gear attachment 5. One can, with an acceptable error value, write the expression for the torque of this clutch as

$$M_{\text{tor}} = k_m t, \quad (1)$$

where k_m is the mechanical constant of the clutch, determined by the ratio of the average torque of the clutch to the time of its engagement.

Engagement of the electromagnetic friction clutch is accomplished in two stages:

1. The time period from the beginning of engagement of the clutch control winding to the occurrence of

$M_{\text{tor}} = M_1$. Here, M_1 is the moment of force of the driven part. During this period, the driven part is immobile, and all of the

supplied energy is expended for overcoming the forces of sliding friction. In turn, this stage can be divided into two periods: a) the period from the moment of engagement of the clutch winding to the moment when the gap between plates will be equal to zero; during this period, the time of "jump-over" of the anchor is determined by the forces of the magnetic field; b) the period up to the occurrence of $M_{\text{rot}} = M_1$.

2. The time period from the beginning of rotation of the driven part to the occurrence of full engagement of both parts of the model. The duration of this period is determined by means of the combined solution of the equations of motion of the driven and driving parts.

Insofar as a rigid connection of the indicated parts of the model is formed with the moment and slip of the auxiliary engine, which generally do not correspond to the moment of force of the driven part, acceleration or slowing of the entire system to a speed corresponding to the moment of force is the final stage of the transient process.

Thus, the total time of the transient process of engagement of the microdrive is

$$t_r = t_0 + t_1 + t_2 + t_3 \text{ sec.} \quad (2)$$

where t_0 , t_1 , t_2 are the time of the "jump-over" of the anchor of the clutch, and the first and second stages of engagement of the clutch, respectively, in seconds; t_3 is the time of acceleration or slowing of the system, in seconds.

The dynamics of a disconnectable microdrive have their own specific features under the conditions of inspection of the shaft and hauling up of containers. Therefore, it is advisable to examine these conditions separately.

Conditions of inspection of the shaft and cables. In the period preceding engagement of the microdrive, the driven part is immobile and the driving part rotates with an angular velocity ω_2 . The equation of motion of the driving part has the form

$$M - M_{2s} - M_{\text{res}} = J_2 \frac{d\omega_2}{dt}, \quad (3)$$

where M is the present moment of the auxiliary engine, in nm; M_{2s} is the moment of force of the losses of the driving force of the model, in nm.

All of the parameters included in (3) and subsequent equations are relative to the shaft of the clutch.

We will assume that the mechanical characteristic of the auxiliary engine is linear, i.e.

$$M = \frac{M_R}{s_R} s, \quad (4)$$

where M_R is the rated moment of this engine, in nm; s_R and s are its rated and current slip.

Switching from the angular velocity ω_2 to the slip s , we obtain the differential equation of slip of the driving part of the model after simple transformations

/1004

$$\frac{ds}{dt} + \frac{1}{T_2} s = k_2 (M_{2s} + k_2 t), \quad (5)$$

where T_2 is the electromechanical constant of the driving part of the model;

k_2 is a coefficient.

Taking into account the fact that expression (1) takes

place with $t < T$, we find the general solution of equation (5) as

$$s = Ce^{-\frac{t}{T_1}} + k_2 T_1 M_{1s} + k_3 T_1 k_u t - k_3 T_1^2 k_u \quad (6)$$

Substituting the values of the parameters of the model

$$T_2 = 0.57; k_2 = 0.098; k_u = 315; M_{1s} = 1.2$$

into (6) and proceeding from the initial conditions: $t=0$, $M=M_{1s}$, we find the partial solution of (5) in the first stage for the ratio $J_1:J_2=1.1$.

$$s = 0.97e^{-1.75t} + 1.7t - 0.9635 \quad (7)$$

With $t > T$, the torque of the clutch M_{Tor} is a constant, and the general solution of equation (5) has the form

$$s = Ce^{-\frac{t}{T_1}} + k_2 T_1 (M_{1s} + M_{Tor}) \quad (8)$$

Substituting the values of the parameters into (8) and taking into account that, with $t=T$, the slip s is determined from (7), we find the value of the constant of integration and the partial solution of (5) in the second stage

$$s = 0.142 - 0.1285e^{-1.75t} \quad (9)$$

The slip curve of the driving part of the model $s(t)$, in accordance with (7) and (9), is given in figure 2.

The equation of motion of the driven part of the model has the form:

$$M_{Tor} - M_{1s} - M_{1\omega} = J_1 \frac{d\omega_1}{dt} \quad (10)$$

where M_{1s} is the moment of force of the losses of the driven part of the model, in nm; ω_1 is the angular velocity of rotation of the driven part, in rad/sec.

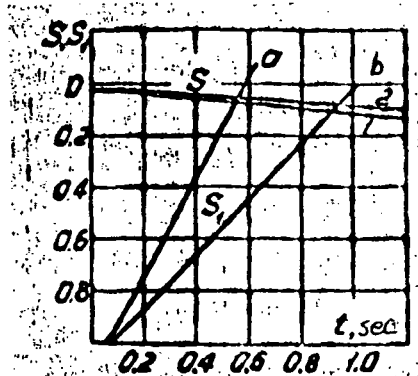


Fig. 2. Graphs of the slip of the driving $s(t)$ and driven $s_1(t)$ parts of the model under conditions of inspection of the shaft and cables with $J_1:J_2=1.1$ (1) and 0.6 (2) and $M_1=0$ (a) and $0.5 M_R$ (b).

Switching in a similar manner from the angular velocity ω_1 to the slip s_1 , after simple transformations, we obtain the differential equation of the slip of the driven part of the model

$$\frac{ds_1}{dt} = k_1(M_1 + M_{1s}) - k_1 k_m t, \quad (11)$$

where k_1 is a coefficient.

The general solution of equation (11) has the form: in the first stage with $t < T$

$$s_1 = C - \frac{1}{2} k_1 k_m t^2 + k_1 (M_1 + M_{1s}) t, \quad (12)$$

and in the second stage with $t > T$

/1005

$$s_1 = C + k_1 (M_1 + M_{1s} - M_{1\text{res}}) t. \quad (13)$$

The partial solutions of equation (13) are found by similar means. The calculation graphs of the slip of the driven part of the model $s_1(t)$ are given in figure 2. The points of intersection of the curves $s(t)$ and $s_1(t)$ correspond to the moments of full engagement of both parts of the model. In this case, the graphic solution of the system of equations makes it possible to simply and graphically determine the slip s_2 and the time t_2 which correspond to full engagement of the clutch plates. It should be noted that the analytic solution of this very system of equations is very complex, in spite of their comparative simplicity.

In the period t_3 , the system accelerates up to an established slip s_3 . The nature of the system's motion during

this period is determined by the form of the mechanical characteristic of the auxiliary engine, and the duration—according to the commonly-known expressions.

Given in figure 3 are the graphs of the relative moment of the auxiliary engine $\frac{M}{M_R}(t)$ and the slips of the driving $s(t)$ and driven $s_1(t)$ parts of the model in the transient process, established by calculation and test means.

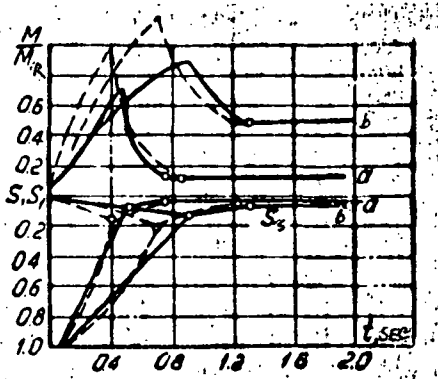


Fig. 3. Graphs of the moment of the auxiliary engine and slip of the parts of the model under conditions of inspection of the shaft and cables, with $J_1:J_2=1.1$; $M_1=0$ (a) and $0.5 M_R$ (b).

Comparison of the results of the theoretical and experimental study of the dynamics of the model shows the sufficient similarity of the calculation (solid) and test (dotted) curves of the transient process. The discrepancies in the calculation and test values do not exceed 8-15%, with the model parameters indicated above, for the relative moment of the auxiliary engine, and 5-13% for the time of the transient process.

Conditions of hauling up of containers. In the period preceding engagement of the model, the driving part rotates with an angular velocity ω_2 , and the driven part is slowed from a velocity $\omega_1 > \omega_2$ to a velocity ω_M . With reduction of the velocity of the driven part to a velocity ω_M , the velocity relay functions and the clutch winding is engaged, which is the beginning of the transient process. With engagement of the clutch plates, the driven part is slowed sharply and the driving portion can be accelerated.

The equation of motion of the driving part of the model has the form

$$M - M_{is} + M_{\tau\alpha} = J_2 \frac{d\omega_2}{dt} \quad (14)$$

By solving equation (3) in a similar manner, we obtain the differential equation of slip of the driving part of the model

$$\frac{ds}{dt} + \frac{1}{T_1}s = k_2(M_{2s} - k_{\alpha}t) \quad (15)$$

The general solution of this equation has the form: in the first stage of engagement of the clutch, with $t < T$

$$s = Ce^{-\frac{t}{T_1}} + k_2 T_1 M_{2s} - k_2 T_1 k_{\alpha} t + k_2 T_1 k_{\alpha} T \quad (16)$$

and in the second stage, with $t > T$

$$s = Ce^{-\frac{t}{T_1}} + k_2 T_2 (M_{2s} - M_{\tau\alpha}) \quad (17)$$

/1006

The constants of integration in these equations are determined from those very same initial conditions as in equations (6) and (8). By substituting the values of the parameters into (16) and (17) and determining the integration constants, we find the partial solutions of equation (15) as:

for the first stage of engagement of the clutch

$$s = 0.97e^{-1.75t} - 1.7t + 0.9765 \quad (18)$$

and for the second stage

$$s = 0.1265e^{-1.75t} - 0.128 \quad (19)$$

The slip curves of the driving part of the model $s(t)$, in accordance with (18) and (19), are given in figure 4.

The equation of motion of the driven portion of the model has the form

$$-M_{\tau\alpha} - M_1 - M_{is} = J_1 \frac{d\omega_1}{dt} \quad (20)$$

After simple transformations, we obtain the slip equation of the driven part of the model

$$\frac{ds_1}{dt} = k_1 k_n t + k_1 (M_1 + M_{1s}), \quad (21)$$

Its general solution has the form: in the first stage of engagement of the clutch

$$s_1 = C + \frac{1}{2} k_1 k_n t^2 + k_1 (M_1 + M_{1s}) t, \quad (22)$$

and in the second stage

$$s_1 = C + k_1 (M_1 + M_{1s} + M_{ron}) t. \quad (23)$$

The partial solutions of equation (21) are found by similar means. The calculation graphs of the slip of the driven part of the model are given in figure 4. Examined here are two cases of engagement of the clutch winding: with $s_s = -0.25$ (I) and -0.1 (II). The intersection of the graphs

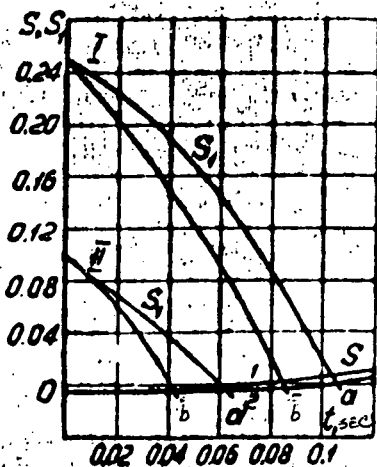


Fig. 4. Graphs of slip of the driving $s(t)$ and driven $s_1(t)$ parts of the model under conditions of the hauling up of containers with $J_1:J_2=1.1$ (1) and 0.6 (2); $M_1=0.5 M_R$ (a) and M_R (b); $s_s=-0.25$ (I) and -0.1 (II).

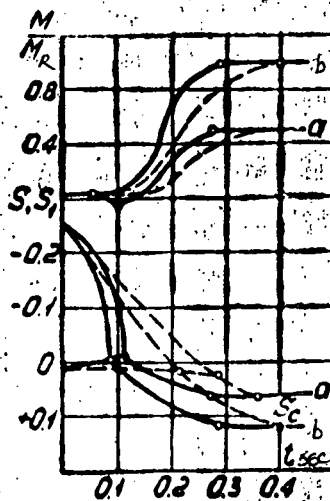


Fig. 5. Graphs of the moment of the auxiliary engine and the slip of the parts of the model under conditions of the hauling up of containers, with $J_1:J_2=1.1$; $s_s=-0.25$; $M_1=0.5 M_R$ (a) and M_R (b).

of $s(t)$ and $s_1(t)$ give a graphic solution of the system of equations (15) and (21).

In the period t_3 , both parts of the model are tightly engaged, and the system is slowed down to an established slip s_s , corresponding to the moment of force of the driven part. The regularity of motion of the system is determined, in this case, by means of the mechanical characteristics of the engine, and the duration of the period—according to the well-known expressions.

/1007

Given in figure 5 are the graphs of the relative moment of the auxiliary engine $\frac{M}{M_R}(t)$ and the slips of the driving $s(t)$ and driven $s_1(t)$ parts of the model during the transient process, established by calculation (solid) and test (dotted) means. Comparison of these graphs shows the sufficiently close similarity of the calculation and test data. The discrepancy in the values of these data from the model parameters examined above does not exceed 11-20%.

If one takes into account that the moment of force does not exceed $0.7 M_R$ during the hauling up of containers [3], then the error of 20% is quite acceptable during engineering calculations.

The graphs given in figures 3 and 5 characterize the dynamics of a model of a microdrive with an electromagnetic friction clutch as quite favorable. Because of the smooth increase in the torque of this clutch, there occurs a monotonous nature of the load on the auxiliary engine and the change in the rates of rotation of the driving and driven parts of the model during the transient process. The load moment of the auxiliary engine of the model, with the para-

meters of the latter being studied, does not exceed $1.2 M_R$ under conditions of inspection of the shaft and cables, and does not exceed the static under conditions of the hauling up of containers. Consequently, the utilization of an electromagnetic friction clutch as the control element of a disconnectable microdrive makes it possible to substantially modify the dynamics of the latter and simplify the operating conditions of the auxiliary engine.

Conclusions

1. The favorable dynamics of the studied model of a disconnectable microdrive with an electromagnetic control friction clutch indicates the advisability of the development and use of a two-speed microdrive for hoisting machines with the indicated clutch.

2. In connection with the practical absence of overloading of the microdrive in the transient process, the parameters of the latter can be established on the basis of static calculations.

3. The procedure given in the study for calculating the transient process of an electric drive with an electromagnetic friction clutch is characterized by simplicity and a permissible error magnitude, in connection with which it can be utilized in engineering practice.

Appendix

The general solution of equation (5) is obtained in the following manner:

$$\begin{aligned} s &= e^{-\int \frac{1}{T_2} dt} \left[\int k_2 (M_{2s} + k_u t) e^{\int \frac{1}{T_2} dt} dt + C \right] = \\ &= C e^{-\frac{t}{T_2}} + k_2 e^{-\frac{t}{T_2}} \int M_{2s} e^{\frac{t}{T_2}} dt + k_2 k_u e^{-\frac{t}{T_2}} \int t e^{\frac{t}{T_2}} dt = \\ &= C e^{-\frac{t}{T_2}} + k_2 T_2 M_{2s} + k_2 k_u T_2 t - k_2 T_2^2 k_u. \end{aligned}$$

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